Determining Stream and Wetland Health in an Urban Restored Riparian Ecosystem in Durham NC through Benthic-macroinvertebrate Surveys

by
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Abstract

Water and aquatic habitat quality are frequently assessed by analyzing the structure of macroinvertebrate communities in streams and other bodies of water. The Stream and Wetland Assessment Management Park (SWAMP) in Durham, NC is a restored stream and wetland complex started in 2003. Restoration phases have been constructed to target both improvements in water quality and habitat. Chemical and microbial laboratory analysis has shown that the water quality has improved since the restoration. Benthic macroinvertebrate data collected three times, over an 8-year period demonstrate dissimilar results. The macroinvertebrate community analysis shows an overall decrease in both water and habitat quality since the restoration. There is also a significant difference in the macroinvertebrate communities found between restoration phases. These findings are contrary to the expected results for stream and wetland restoration projects, but may be due to unusually high stream discharges in recent years compared to earlier survey periods.

Introduction

Study Area

The Stream and Wetland Assessment Management Park (SWAMP) in Duke Forest is a restored wetland and stream complex on Sandy Creek which feeds into the Jordan Lake drinking reservoir (Richardson et al. 2011). It is part of the Cape Fear River Basin, sub-basin 03-06-05 which includes New Hope Creek, Northeast Creek and Jordan Lake (DWQ 2005) (See Figure 1). The area overlies the Triassic Basin, giving it a unique geology and sandy soils. SWAMP drains an area of about 600 hectares; of that area approximately 140 ha, or 23% of the drainage are classified as "undeveloped" and 460 ha, or 77% of the drainage are classified as "developed" in the 2006 National Land Cover data set (Fry 2011) (See Figure 2).

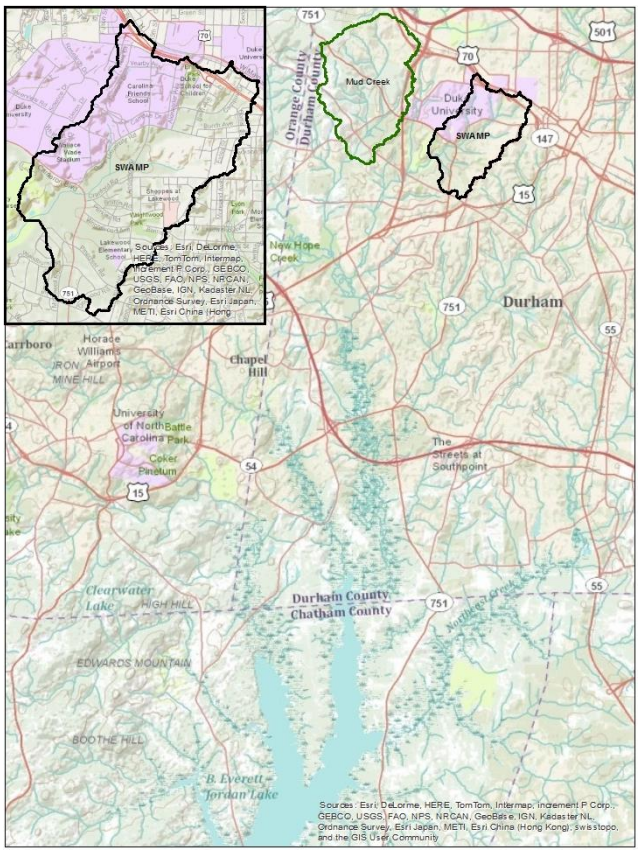

Figure 1: Location of the restored SWAMP study site and the Mud Creek reference site drainage basins in Durham County NC.

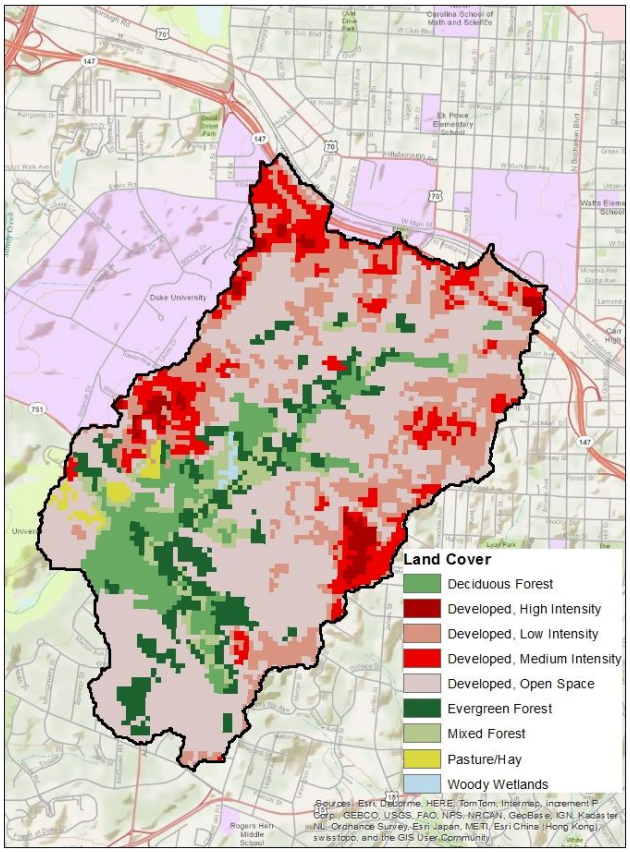

Figure 2: 2006 Land cover classes in SWAMP drainage area of Durham, NC (Fry 2011).

Restoration

The section of Sandy Creek on Duke's campus was extremely impaired, meaning the waters were highly polluted with excess sediment, nutrients and other non-point source pollutants (Richardson et al. 2011). Restoration efforts were undertaken in phases starting in 2003, four have been completed, and a fifth is currently under construction (Richardson 2014). The first two phases included re-sculpting the geomorphology of the main stream channel and constructing a retention pond and dam; these adjustments allow the stream to be connected with its floodplain more frequently, promoting advantageous biogeochemical processes, and the pond allows sediment to settle out before the water travels downstream (Richardson et al. 2011). The fourth phase is an anabranching, or braided stream design which aimed to maximize water quality improvements by reconnecting the stream to its floodplain, as well as increase sediment retention in the floodplain, lowering the suspended solid levels in the stream (Richardson 2014). These two sections of SWAMP, the main stem and the stream channel of the anabranching phase, will be the focus of this study.

The restoration efforts on the main stem of Sandy Creek have proven to be a success through measured reductions of nitrogen, phosphorous, fecal coliform bacteria, and total suspended solids; however, improvements to habitat have not been as clear cut (Richardson et al. 2011). The results on the effectiveness of the fourth, anabrancing, phase to improve water quality have not yet been published. Additionally, it has yet to be demonstrated that restoration efforts in Sandy Creek will succeed in providing high quality habitat that is used by a diverse community of animals or at least match the habitat quality of regional reference streams.

In order to address the habitat change over time, two other Master's Projects have been conducted before this study (Roberts 2005, Still 2009). This project compared the change in water and habitat quality over time, as well as the changes in water and habitat quality as assessed by the benthic macroinvertebrate community between restoration phases.

Benthic Macroinvertebrates

Macroinvertebrate diversity has long been used as a proxy for water quality in streams; certain species are not tolerant of polluted waters and certain species are somewhat tolerant of pollution; the presence of intolerant species indicats better water quality (Beck 1955, Hilsenhoff 1982). Macroinvertebrates are commonly used as biological indicators of water and habitat quality for several reasons including - they are found in all aquatic environments, are relatively sessile so they are exposed to any pollutants that come into the stream, and are relatively easy to collect (DENR 2012). Benthic macroinvertebrate communities provide a picture of both the current and long and short term water quality (DENR 2012). Low diversity indicates the dominance of a few pollution-tolerant taxa in the system (Barbour et al. 1996).

Quantifying the presence of these organisms at stream sites to the genus or species level can provide a biotic index that indicates the cleanliness of the water (Beck 1955, Hilsenhoff 1982). North Carolina has its own Biotic Index (NCBI) that is used by the Department of Environment and Natural Resources, Division of Water Quality which was designed to measure a variety of stresses that either lower the abundance of sensitive taxa or promote the abundance of pollution-tolerant taxa (Lenat 1993). The NCBI is based on the biotic index developed by Hilsenhoff in 1977(Lenat 1993).

Benthic macroinvertebrates can also be classified by feeding groups, which also indicate recent disturbances to the system and the dominant processes in the ecosystem (Barbour et al. 1996, Rawer-Jost et al. 2000, Merritt and Cummins 2011). There are five functional feeding groups that invertebrates found in the Sandy Creek system might fall into, each indicates the type of food particles that an organism tends to focus on as well as the structural and behavioral adaptations to obtain the food (Merritt and Cummins 2011). Shredders (SH) tend to chew leaves, which are classified as coarse particulate organic matter (CPOM). Collectors fall into two categories – gathering (GC) and filtering (FC); both feed on fine particulate organic matter (FPOM), GC focusing on CPOM deposited on surfaces and FC on those

particles suspended in the water column. Scrapers (SC) consume algae and associated material that may be growing on surfaces in the stream. Predators (PR) consume other macroinvertebrates. The dominant functional feeding group (FFG) found indicates the dominant food source present in the system (Merritt and Cummins 2011), as well indicates the quality of the stream. More specialized feeders including predators and shredders indicate better water quality while an abundance of collecting feeders indicated poorer water quality (Barbour et al. 1996).

Objectives

The goals of this study are two-fold. The first is to determine if the habitat and water quality of the restored stream have improved over time. The second objective is to determine if the anabranching phase of the restoration has shown an improvement in water quality and habitat in the stream channel as compared to the main stem where there is less interaction with the soil and the beneficial biogeochemical processes that occur in the soil.

The hypotheses that were tested during this study were

1) As time since restoration increases, the water quality and habitat formation will increase, which will be reflected by a diverse and pollution intolerant benthic macroinvertebrate community.
2) The stream channel in the anabranching site will demonstrate higher water quality through the NCBI in addition to the taxa and FFG analysis when compared to the same measures for the main stem.

Methods

Sites

Eight sites were sampled for this study in the summer of 2013. Three sites were located along the main stem of SWAMP, three along the stream channel of the anabranching phase (See Figure 3), and two at a reference stream in the same watershed, Mud Creek. These sites were chosen 1) to allow a comparison between this study and those completed in the past, 2) to allow comparison between the main stem and the anabranching phases, and 3) because Mud Creek has served as a reference stream for all of the other phases of restoration.

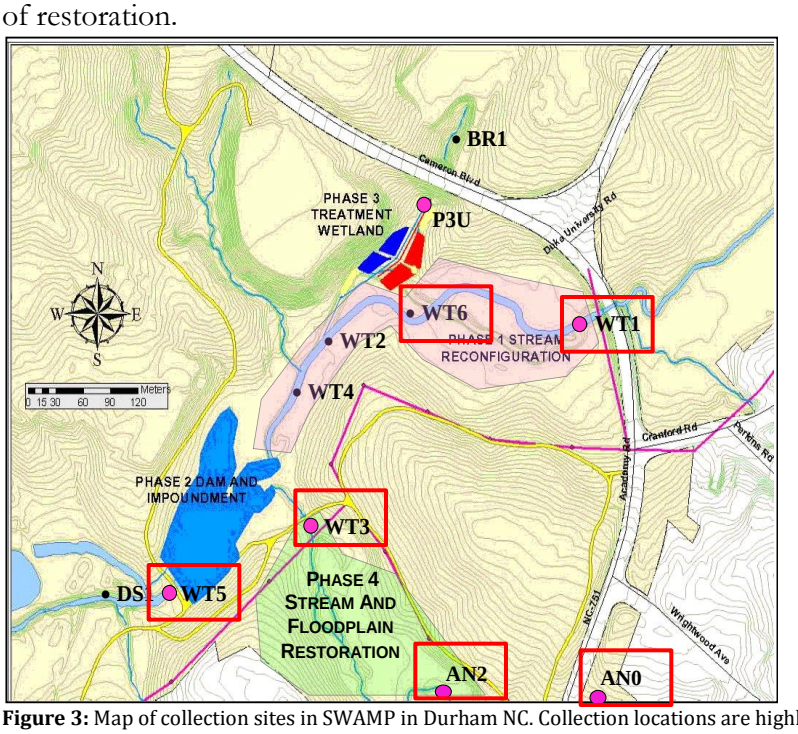

Figure 3: Map of collection sites in SWAMP in Durham NC. Collection locations are highlighted with red boxes.

Data Collection

The North Carolina Division of Water Quality's (NC DWQ) *Standard Operating Procedures for Benthic Macroinvertebrates* (2012) outlines four types of sampling methods that may be employed, each is suited for a specific type of environment.

1) Standard Qualitative Method: is comprised of several sampling methods and is suited for most wadeable flowing streams in NC. It can be used to assign water quality ratings to these bodies.
2) EPT (Ephemeroptera, Plecoptera and Trichopetera orders of insects), Method: an abbreviated version of the standard qualitative technique, and is only used to quicky determine the differences in water quality between sites. It is especially useful in studies that require a large number of samples.
3) Qual 4 Method: also an abbreviated sampling method like the EPT but with one additional log/rock wash sample. This method is intended for exceptionally small streams with very few EPT taxa
4) Swamp Method: for streams that stop flowing in summer months, typically used in coastal regions. In this case, sampling must be done in the winter and should use a variety of techniques.

The NC DWQ methods are intended to assess an entire stream (DENR 2012). Since this study is comparing parts of the same stream, I used a modified version of the North Carolina Division of Water Quality's *Standard Operating Procedures for Benthic Macroinvertebrates* (2012) to collect benthic macroinvertebrates in SWAMP and the Mud Creek reference site. The two previous studies also used these methods, so by using identical methods, the results will be more directly comparable. More specifically, a modified version of the standard qualitative method, the most detailed and thorough collecting methodology, was used to provide the best "snapshot" of water quality and habitat in Sandy Creek.

The standard qualitative method calls for two kick-net samples, three sweep-net samples, one leaf-pack sample two fine-mesh rock or log wash samples, one sand sample and a visual collection at each collection site (DENR 2012). The modified methods used at each collection site were one kick net sample, one sweep net, one leaf-pack, and 2-3 rock- or log-washes (Still 2009). A kick net is comprised of a double layer of screen between two poles. To take a sample, the net is placed upright in a riffle of the streambed and the area upstream of the net is disturbed by kicking for approximately one minute, dislodging many macroinvertebrates and capturing them in the downstream net (See Figure 4). The contents of the net are then washed through a sieve, which will allow water and small sediment to fall through, and larger macroinvertebrates to remain on top. A sweep net sample is taken using a hand-held D-frame net on a pole to sweep areas near the banks including woody debris snags and root clumps (See Figure 5). The contents of the sweep samples are also washed through a sieve. A leaf-pack sample is taken by collecting three or four clumps of decaying leaves found in the stream and pouring water over them to wash any animals into the sieve, this method typically collects more invertebrates in the "shredder" feeding group. The fine-mesh samples involve washing rocks or small logs that are covered in moss or another type of cover into a fine mesh to collect very small animals that may not have been collected in the mesh of the previous sampling types. Finally, a visual sample is taken by over-turning rocks and logs at random locations in the stream channel and collecting any organisms found with forceps (See Figure 6). The samples from each site were combined and transported back to the lab for identification. (DENR 2012)

Figure 4: Kick net collection along the main stem of SWAMP in June 2013

Figure 5: Sweep net collection along main stem of SWAMP in June 2013.

Figure 6: Visual inspection at main stem of SWAMP, June collection in 2013**.**

Analysis

Individuals collected were identified at least to the genus, and to species as time and resources allowed. *Chironomidae* identification was predominantly conducted by Erick Fleek, PhD of the NC DWR; Dave Lenat, PhD formerly of the NC DWQ; and Wendell Pennington of Pennington and Associates Environmental Consulting. Table 1 lists the abundances of orders found at each site in 2013, and 2008 and 2005 abundances can be found in Table 2.

Table 1: 2013 abundances of each order at collection sites (See Figure 3 for sampling locations).

	Anabranching, Phase 4			**Main Stem of SWAMP**			**Mud Creek**		**2013**
Order	*AN-0*	*AN-2*	*WT-3*	*WT-1*	*WT-6*	*WT-5*	*MC-A*	*MC-B*	**Totals**
Annelida	0	0	0	1	2	1	0	0	4
Diptera	36	38	26	82	79	29	87	58	435
Gastropoda	3	4	3	2	0	3	0	2	17
Odonata	26	3	1	1	2	5	1	7	46
Oligochaeta	7	1	23	4	1	4	0	1	41
Ephemeroptera	0	0	1	7	3	0	9	2	22
Bivalvia	0	2	1	0	0	9	0	10	22
Trichoptera	0	2	7	35	54	2	24	2	126
Coleoptera	0	0	0	0	2	0	3	1	6
Decapoda	0	0	1	0	0	0	2	2	5
Plecoptera	0	0	0	0	0	0	0	0	0
Totals	72	50	63	132	143	53	126	85	724

Table 2: 2008 and 2005 abundances of orders at collection sites.

Order	**WT-1 2008**	**WT-6 2008**	**WT-5 2008**	**MC 2008**	**2008 Totals**	**2005**
Annelida	11	11	4	1	27	5
Diptera	30	54	34	32	150	38
Gastropoda	4	5	3	2	14	12
Odonata	1	0	4	0	5	32
Oligochaeta	12	4	3	2	21	3
Ephemeroptera	1	1	2	1	5	14
Bivalvia	0	1	0	1	2	4
Trichoptera	30	33	1	21	85	20
Coleoptera	10	5	4	26	45	0
Decapoda	0	0	0	22	22	1
Plecoptera	0	0	0	1	1	1
Totals	99	114	55	109	377	130

Each genus and species has been assigned a tolerance value for North Carolina, which indicates its ability to withstand pollution (Lenat 1993, DENR 2012). These values were used to calculate a biotic index (See Equation 1) for each restoration phase in SWAMP, and at the reference site indicating the water quality for each (DENR 2012). The information on number of individuals in each genus or species group was also used to calculate a Shannon-Weiner Index (See Equation 2) value, which indicates the diversity of a site. An evenness index was also calculated to indicate the distribution of abundance across the taxa present (See Equation 3)

Equation 1: Biotic Index

$$B = \sum \frac{(Ti)(ni)}{N}$$

B= the biotic index
Ti = tolerance value for each taxon
ni = abundance for each taxon
N = sum of all abundance values; total number of individuals in the population

(DENR 2012)

Equation 2: Shannon-Weiner Index

$$H' = -\sum_{i=1}^{s} pi \ln(pi)$$

H' = the Shannon-Weiner Index
s= number of taxa
ni = abundance of each taxon
N= sum of all abundance values; total number of individuals in the population
pi = relative abundance of each taxon, calculated as the proportion of individuals of a given taxon to the total number of individuals in the community : $\frac{ni}{N}$

(Shannon 1948)

Equation 3: Evenness Index

$$J' = \frac{H'}{\log_2 S}$$

S=number of taxa

(Cao et al. 1996)

Results

Biological Index

The NCBI decreases over time, and is lower for the stream channel in the anabranching phase than the main stem of SWAMP. The biotic index for the reference site, Mud Creek stayed the same over time (See Table 3 and Figure 8). There was no improvement in the NCBI from 2008 to 2013. In fact, the overall output for SWAMP shows a biotic index value that is higher than that calculated in either 2005 or 2008, indicating much poorer water quality. As opposed to the results in 2008, Mud Creek, the reference site had a lower biotic index, indicating better water quality, than the SWAMP sites.

Table 3: The Biotic Index values for all collection sites on Sandy Creek and Mud Creek for 2005, 2013 and 2008.

Location Description	2013 Biotic Index	2008 Biotic Index	2005 Biotic Index
Anabranching (stream only)	7.8		
Main Stem	7.0	6.5	6.7
Reference: Mud Creek	6.6	6.9	

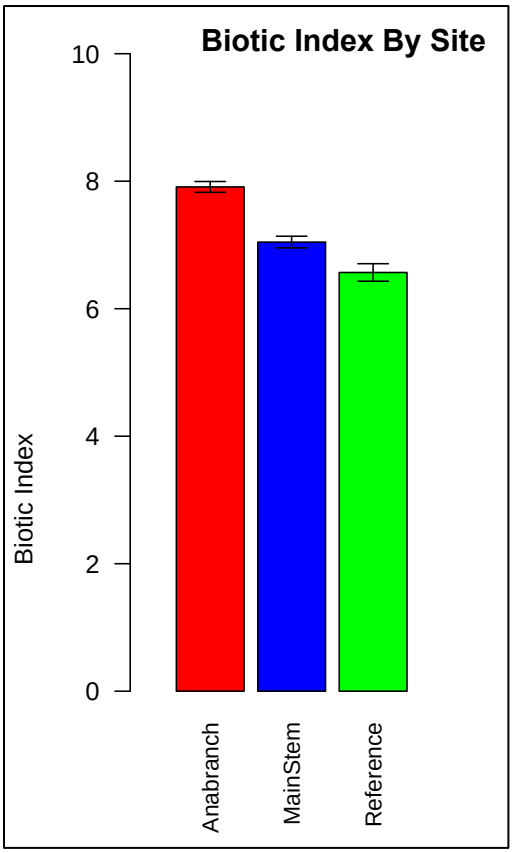

Figure 7: This bar graph displays the composite NCBI for each collection site in 2013.

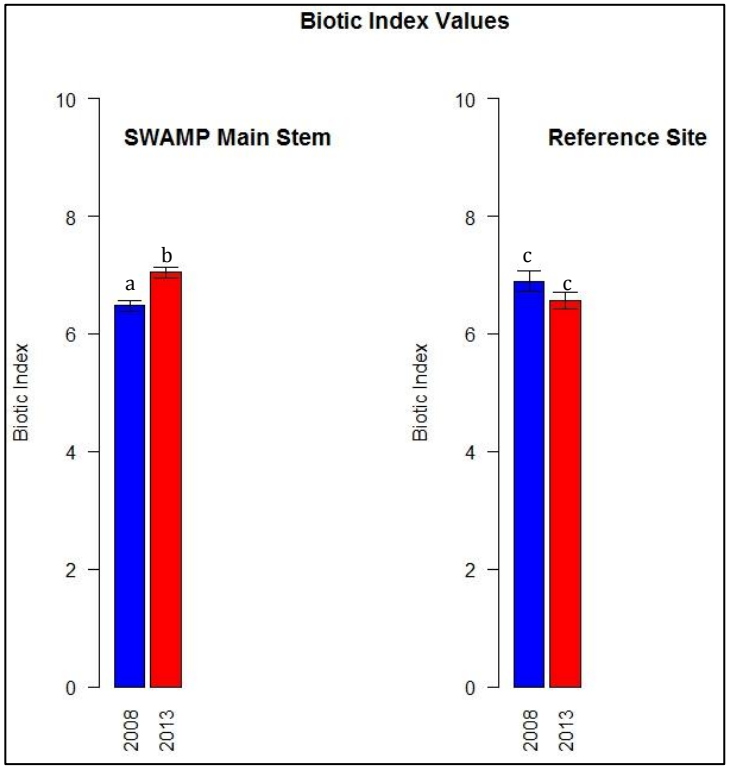

Figure 8: This bar graph shows the NCBI values for the Main Stem and reference site over time.

An analysis of variance of the biotic index values at each site was conducted, and was found to have a significant difference between sites (df=2, p-value = $<2 \times 10^{-16}$). Further investigation with a Tukey honest significance difference test revealed that the difference is significant at the 95% confidence level between all of the sites (p-value = 0.00 for all three site comparisons) (See Figure 7).

A t-test of the NCBI values for the main stem and reference site in both 2008 and 2013 was conducted and a significant difference at the 95% confidence level was found to be evident between the sampling dates on the main stem of SWAMP, but not between the reference site sampling dates (main stem p-value= 0.00, reference p-value=0.14). Looking at the data, it appears that the NCBI has increased over time at the study site (See Figure 8).

Shannon-Weiner Index

The Shannon-Weiner Index data mirrors the results from the biotic index- a decrease in diversity over time (See Table 4). However, in this case, the reference reach also has a lower diversity index value in 2013 than in 2008. Evenness also decreases over time, indicating the dominance of a few pollution-tolerant species. Original data was not available for 2005, and the evenness had not previously been calculated as the Shannon-Weiner Index had been in the 2008 study by Still (2009).

Table 4: Shannon Weiner Indices and Evenness for 2013, 2008 and 2005.

Location Description	H' (Shannon –Wiener Index)	Evenness
Anabranching 2013 (stream channel only)	2.2	0.36
Main Stem 2013	2.3	0.38
Reference 2013	2.5	0.41
Main Stem 2008	2.6	0.53
Reference 2008	3.3	0.67
Main Stem 2005	3.4	n/a

Order Fractions

Across the board, Diptera (true flies) larvae were the dominant organisms found at all of the sites. Occasionally, other organisms were more dominant. For instance, in May stream channel of the anabranching site, Gastropoda (snails) were the dominant organism collected, and in July at the main stem of Sandy Creek, Trichoptera (Caddisflies) were almost equal to the number of Dipterans (See Figure 10). This data shows the dominance of a few taxa collected in the summer of 2013, indicating poor water quality.

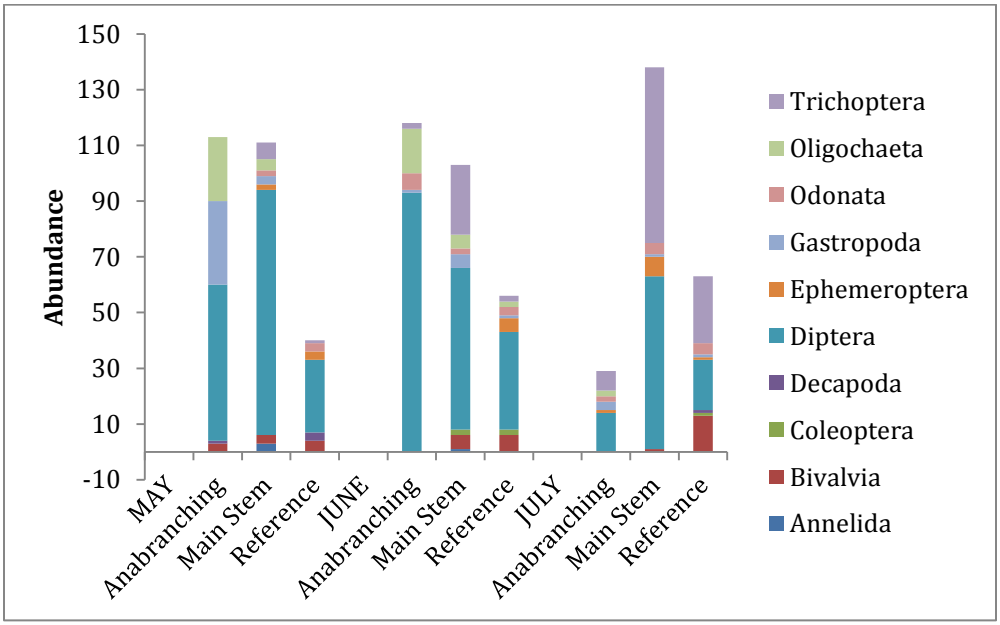

Figure 9: The cumulative Order-composition of the samples collected at each study site for each of the three collection periods in the summer of 2013.

Functional Feeding Groups

The two collector FFGs, GC and FC are the most abundant at all sites, at all collection dates. This indicates that there is a large amount of fine particulate organic matter (FPO) in the water. Over time, the FC abundance increases especially in the main stem and reference sites, indicating an increase in the suspended FPO over the season. These data are similar to the Order data in that there are two dominant groups in the system.

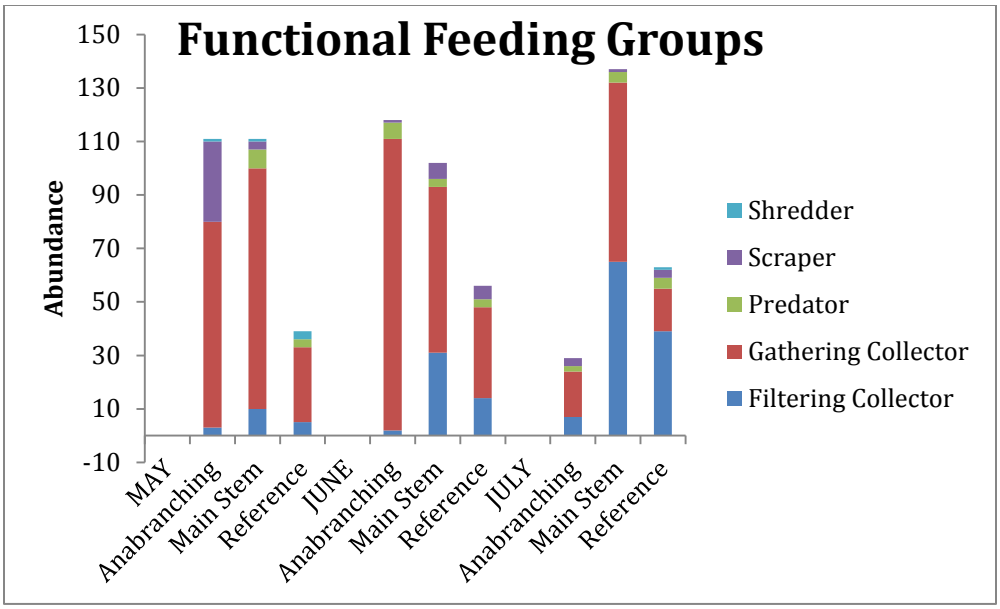

Figure 10: Aggregated functional feeding group (FFG) data for each collection site and date in 2013.

Discussion and Conclusion

The first hypothesis tested in this study was that as time since restoration increases, the water quality and habitat formation will increase, which will be reflected by a diverse and pollution intolerant benthic macroinvertebrate community. To test this, I analyzed the North Carolina Biotic Index for the macroinvertebrate community, as well as the species richness and evenness of the sites over time. While there was a change detected over time, it was not the improvement from 2008 to 2013 that I expected to see, but rather a decrease in water quality over time. The Shannon-Weiner diversity index indicated a decrease in diversity over time as well (See Table 4). The reference site over time, experienced a slight decrease in diversity and the NCBI analysis from 2008 to 2013 as well but it was not significantly different. The decrease in diversity over time at the reference, although not significant may indicate that the decrease in diversity was not caused by anything to do with the restoration, but rather larger scale environmental factors such as changes in rainfall or drought periods.

The second hypothesis tested in this study was that the stream channel at the anabranching site would demonstrate higher water quality through the NCBI of the macroinvertebrate community found there in addition to the taxa and FFG analysis. I also expected to see the presence of higher quality habitat as indicated by the diversity of the macroinvertebrate community. The results did not support this postulated trend. The NCBI for the collection sites was significantly different, and from visual analysis of the data (See Figure 7), it is apparent that the macroinvertebrate community at the anabranching site indicates more polluted waters than that of the main stem of SWAMP or the reference site. The Shannon-Weiner diversity index does not show a clear trend either; the richness of the anabranching stream channel site is only slightly different than that of the main stem, and the evenness for both sites are equally low (See Table 4).

Over both time and between restoration phases the results from this study were not what was expected – an improvement in water and habitat quality over time, as well as better water and habitat quality in the stream channel of the anabranching phase of the restoration. Given these unexpected results, I began looking for some possible explanatory factors such as precipitation and stream flow for both 2008 and 2013. The precipitation data showed higher levels of precipitation in 2013 than in 2008 (See Figure 11a). Corresponding with this, the flows through SWAMP for 2013 were much higher than those recorded in 2008 (See Figure 11b). In 1974, Cummings reported that repeated high flows could effectively "reset" a stream ecosystem, resulting in a low biodiversity. It is likely that during the summer of 2013, the SWAMP experienced a "reset" due to high precipitation and discharge volumes.

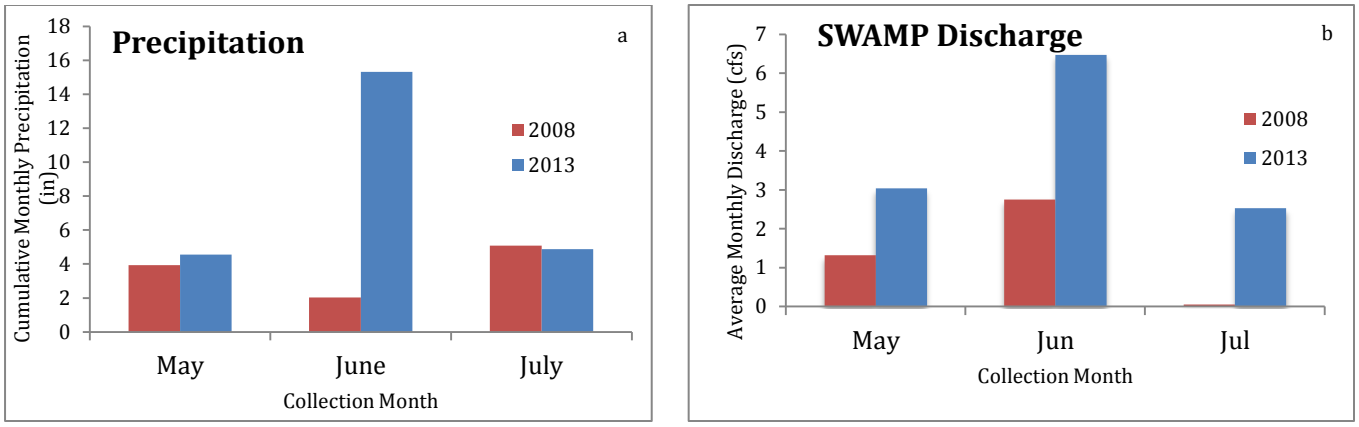

Figure 11: a) Cumulative monthly precipitation from the collection months in both 2008 and 2013. b) SWAMP stream discharge as measured by the Duke University Wetland Center in the 3 summer collection months of both 2008 and 2013.

Future Recommendations

If a more accurate and in-depth analysis is to be made, samples should be collected on a more frequent basis to assess year-to-year conditions of the stream. Increased frequency of sampling would also allow for the inclusion of changes in flow and water quality due to large-scale weather patterns.

The data for WT-5 should be considered with a grain of salt, as it is located below a dam, in a non-restored section of stream. This location receives extremely high flows during storms and is also filled with large pieces of concrete from previous constructions, making it not an ideal habitat for benthic macroinvertebrates. In future studies this collection site should likely not be included, instead a sample taken on the channel upstream of the retention pond might be a better point to analyze the benthic macroinvertebrate community residing in the water leaving SWAMP.

Conclusions

The benthic macroinvertebrate data shows that the water quality in the SWAMP is not improving over time, while other analyses show that the water quality is improving (Richardson et al. 2011). These contradicting results can be explained by the extremely high precipitation levels and stream discharge volumes experienced in the summer of 2013 during sampling. As suggested by Cummins (1974), the repeated high-volume flows likely caused a "reset" of the ecological system, resulting in a stream ecosystem without much diversity in benthic macroinvertebrates. However, I cannot be certain that this is the explanatory factor due to the large gaps in time between benthic macroinvertebrate data sets. For the results of this study or similar studies to have more explanatory power, the studies must be conducted more frequently so that patterns can be more clearly discerned.

Resources

Barbour, M., J. Gerritsen, R. Griffith, R. Frydenborg, E. McCarron, J. White, and M. Bastian. 1996. A Framework for Biological Criteria for Florida Streams Using Benthic Macroinvertebrates. Journal of the North American Benthological Society **15**:185-211.

Beck, W. 1955. Suggested Method for Reporting Biotic Data. Sewage and Industrial Wastes **27**:1193-1197.

Cao, Y., A. Bark, and W. Williams. 1996. Measuring the response of macroinvertebrate communities to water pollution: a comparison of multivariate approaches, biotic and diversity indices. Hydrobiologia **341**:1-19.

Cummins, K. W. 1974. Structure and Function of Stream Ecosystems. BioScience **24**:631-641.

DENR, N. 2012. Standard operating procedures for benthic macroinvertebrates.*in* N. D. o. E. a. N. Resources, editor.

Doll, B. 2012. Assessing Eco-geomorphological Condition of Stream Restoration Projects in North Carolina. North Carolina State University, Raleigh, NC.

DWQ, N. 2005. Cape Fear River Basinwider Water Quality Plan.*in* D. o. W. Q. North Carolina Department of Environmental and Natural Resources, editor., Raleigh, NC.

Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickham, J. 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States. PE&RS **77**:858-864.

Hilsenhoff, W. 1982. Using a biotic index to evaluate water quality in streams.*in* W. D. o. N. Resources, editor., Madison, Wisconsin.

Lenat, D. R. 1993. A biotic index for the southeastern United States: deriation and list of tolerance values, with criteria for assiging water-quality ratings. Journal of the North American Benthological Society **12**:279-290.

Merritt, R. W., and K. W. Cummins. 2011. Trophic Relationships of Macroinvertebrates.*in* F. R. Hauer and G. A. Lamberti, editors. Methods in Stream Ecology. Elsevier Science, Burlington.

Rawer-Jost, C., J. Bohmer, J. Blank, and H. Rahmann. 2000. Macroinvertebrate functional feeding group methods in ecological assessment. Hydrobiologica **422/423**:225-232.

Richardson, C. J. 2014. Duke University Wetland Center. Research.

Richardson, C. J., N. E. Flanagan, M. Ho, and J. W. Pahl. 2011. Integrated stream and wetland restoration: A watershed approach to improved water quality on the landscape. Ecological Engineering **37**:25-39.

Roberts, B. 2005. A Biological Assessment and Comparison of Sandy Creek in Durham, NC to Similar Creeks in the Triassic Basin of North Carolina. Duke University Nicholas School of the Environment Master's Project.

Shannon, C. E. 1948. A mathematical theory of communication. Bell System Technical Journal **27**:379-423 and 623-656.

Still, J. 2009. A Macroinvertebrate Survey of Sandy Creek in Durham County, NC: A Comparative Study of Post-Restoration and Pre-Restoration Surveys.